



nonfederal authorities' imposition of unreasonable and unjustified restrictions on FCC regulatees operating in interstate commerce.

Respectfully submitted,

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APPENDIX I

**PROPOSED REVISION OF OST BULLETIN NO. 65**

**EVALUATING COMPLIANCE WITH FCC-SPECIFIED  
GUIDELINES FOR HUMAN EXPOSURE TO  
RADIOFREQUENCY RADIATION**

**Prepared for:**

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## INTRODUCTION

This technical bulletin has been prepared for use in evaluating compliance with exposure guidelines for radiofrequency (RF) radiation specified by the Federal Communications Commission (FCC). The bulletin is not designed to establish mandatory procedures. It is meant to provide assistance in determining whether an FCC-regulated facility might create a significant environmental effect due to human exposure to levels of RF radiation in excess of the specified radiation protection guides. Although this bulletin offers guidelines and suggestions for evaluating compliance, other methods and procedures for evaluating compliance may be acceptable, if based on sound engineering practice and scientific principles.

This revised bulletin is being issued to conform to current FCC requirements dealing with the responsibilities of the Commission in controlling human exposure to RF radiation emitted from FCC-regulated transmitters. The Commission has identified human exposure to RF radiation as an issue for explicit consideration when evaluating potential environmental effects of certain facilities regulated by the FCC. Under the National Environmental Policy Act of 1969 (NEPA), the FCC is required to consider whether its actions in licensing or authorizing facilities significantly affect "the quality of the human environment." Exposure to RF radiation is one of several issues the Commission must consider in evaluating environmental significance.

Implementation of NEPA with respect to human exposure to RF radiation was effected initially in a rule change adopted in February, 1985, and made effective January 1, 1986. In that rule change, the RF radiation protection guides issued in 1982 by the American National Standards Institute (ANSI C95.1-1982) were used by the FCC as a threshold for determining whether potentially harmful exposure is possible from an FCC-regulated facility. The 1982 ANSI standard has now been superseded by ANSI/IEEE C95.1-1992 and the rules of the FCC have been revised to incorporate the provisions of the updated standard. Applicants for new facilities, license renewals, or facility modifications in the following categories must inform the Commission if the facility or operation in question would result in human exposure in excess of the 1992 ANSI/IEEE guidelines: (1) broadcast facilities authorized under Part 73 of the FCC Rules and Regulations, (2) television translators, low power television, and experimental broadcast stations authorized under Part 74, (3) satellite-earth transmitting stations authorized under Part 25, and (4) experimental radio stations authorized under Part 5.

The 1992 ANSI/IEEE guidelines differ in a number of respects from those adopted by ANSI in 1982. The frequency range has been extended to include 3 kHz to 300 GHz, compared to the former range of 300 kHz to 100 GHz. Throughout portions of the frequency range, more restrictive criteria have been adopted for uncontrolled environments than for controlled environments. Permissible magnetic field exposures at the lower frequencies have been increased substantially. Finally, maximum limits for induced and contact currents have been specified for frequencies of 100 MHz or less.

This bulletin is organized into six sections: I. Background Information, II. Prediction Methods, III. Measuring the RF Environment, IV. Controlling Exposure to RF Fields, V. References, and Appendices. The Appendices include: (1) a reprint of major sections of the ANSI/IEEE guidelines, and (2) tables and figures to be used in evaluating potential exposure from broadcast facilities. Although this bulletin is designed to be used with reference to all facilities to which the rules apply, its primary application will most likely be in connection with the evaluation of broadcast facilities.

Section I of this bulletin provides details on FCC implementation of NEPA and on FCC procedures relevant to the consideration of RF radiation as an environmental issue. As a first step in evaluating compliance, Section II of the bulletin (Prediction Methods) should be consulted. This section provides information on calculations and other prediction methods and refers the reader to tables and figures found in Appendices B, C, D and E which apply, respectively, to FM, TV, and AM broadcast facilities and to compliance with induced and contact current limits. The proper use of these tables and figures is explained in Section II, and applicants for FM, TV and AM facilities should consult the appropriate subsection of Section II for instructions.

An applicant may be able to secure quick confirmation that a given facility would be in compliance by consulting the appropriate table or figure. However, Section IV of the bulletin (Controlling Exposure to RF Fields) should be consulted also in determining how to comply with the ANSI/IEEE guidelines.

In some cases, such as complex multiple-user locations, measurements of RF fields in the environment may be necessary. Section III of the bulletin provides information on measurement procedures and instrumentation for use in situations where measurements are necessary to demonstrate compliance with the guidelines.

## **Section I: BACKGROUND INFORMATION**

### **FCC Implementation of NEPA**

The National Environmental Policy Act of 1969 (NEPA)<sup>1</sup> requires that all agencies of the U.S. Government take into account the potential environmental impact of their actions. Specifically, agencies must consider whether their actions significantly affect "the quality of the human environment."

The FCC adopted rules in 1974 implementing NEPA with regard to actions taken by the Commission in licensing and approving facilities and operations under its jurisdiction.<sup>2</sup> These rules

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<sup>1</sup> 42 U.S.C. §4321 *et seq.* (1976).

<sup>2</sup> 49 F.C.C. 2d 1313 (1974).

are found in Part 1, Subpart I, of the FCC Rules and Regulations.<sup>3</sup> The Rules provide a list of Commission actions which may have a significant effect on the environment. If Commission approval to construct or operate a facility would result in an environmental effect included in this list, the applicant for such a facility must submit a statement or assessment of the environmental effect including information specified in the Rules. It is the responsibility of the applicant to make an initial determination as to whether environmental information must be submitted and so indicate at the appropriate place on applicable FCC forms. For example, many FCC forms currently incorporate a question whether a grant of the application would be a "major" action under Part 1 of the Rules.<sup>4</sup>

Once environmental information is filed with the Commission, FCC staff determine whether preparation of an "environmental impact statement" is necessary. An environmental impact statement (EIS) is required for any "major" action which would have a significant effect on the environment. However, before preparation of an EIS is initiated, FCC staff may decide that the potential for environmental impact is not great enough to warrant preparation of an EIS and proceed with normal processing of the application. Alternatively, the application may be amended to eliminate or reduce the potential for significant environmental impact. If an EIS is prepared, it must be considered in determining whether or not a grant of the application would be justified. This decision would be based on a careful balancing of the benefits of the action versus the environmental effect, if any. In the case of RF radiation, the environmental effect would be the relative health risk to people living or working near or at the facility in question.

#### RF Radiation and the Environment

In 1979, the Commission released a Notice of Inquiry dealing with the responsibility of the FCC to consider the potential biological effects and hazards of RF radiation when licensing or authorizing facilities or operations emitting such radiation.<sup>5</sup> As a result of comments received in response to this original Notice, and the Commission's assessment of its statutory responsibilities under NEPA, a Notice of Proposed Rule Making was subsequently issued in 1982.<sup>6</sup> The latter Notice proposed to amend Section 1.1305 of the FCC's Rules and Regulations implementing NEPA by expanding the list of "major actions" subject to the Commission's environmental processing procedures. It was proposed that applications for construction permits or licenses to transmit would be treated as "major actions" triggering environmental review if the proposed operation or facility would result in exposure of the public or workers to levels of RF radiation in excess of safe levels.

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<sup>3</sup> 47 C.F.R. §1.1301 *et seq.*

<sup>4</sup> See also, F.C.C. General Docket 79-163, "Amendment of Environmental Rules in Response to New Regulations Issued by the Council on Environmental Quality," Report and Order, 51 Fed. Reg. 14999 (1986) and F.C.C. General Docket 88-387, "Amendment of Environmental Rules," First Report and Order, 55 Fed. Reg. 20396 (1990), Second Report and Order, 56 Fed. Reg. 13413 (1991).

<sup>5</sup> Notice of Inquiry, General Docket 79-144, 44 Fed. Reg. 37008 (1979), 72 F.C.C. 2d 482 (1979).

<sup>6</sup> Notice of Proposed Rule Making, General Docket 79-144, 47 Fed. Reg. 8214 (1982), 89 F.C.C. 2d 214 (1982). Also, 47 Fed. Reg. 10871 (1982) and 47 Fed. Reg. 27384 (1982).

It was the Commission's judgment that it was required to make a determination as to whether the facilities or operations it approves may affect significantly the human environment with regard to emission of RF radiation, regardless of whether the Federal Government officially had issued RF radiation guidelines or standards. Therefore, a Report and Order was issued in March of 1985 amending Section 1.1305 of the Commission's Rules to provide for environmental analysis with regard to human exposure to RF radiation.<sup>7</sup>

The rule amendment applied to actions taken by the Commission with respect to the following: (1) broadcast facilities authorized under Part 73 of the FCC Rules; (2) broadcast facilities authorized under Subparts A and G of Part 74; (3) satellite-earth transmitting stations authorized under Part 25; and (4) experimental radio stations authorized under Part 5. A Further Notice of Proposed Rule Making, accompanying the Report and Order, proposed to categorically exclude other FCC-regulated facilities and operations from the provisions of this rule, except for shipboard satellite-earth terminals.<sup>8</sup> In response to petitions for partial or limited reconsideration and clarification of the Commission's Report and Order, originally slated to become effective on October 1, 1985, a subsequent Memorandum Opinion and Order delayed the effective date of the rule amendment to January 1, 1986.<sup>9</sup> The rule amendment applied to applications for new facilities in the above categories as well as to renewals and modifications of existing facilities.

In its Report and Order, the Commission identified the radiation protection guide issued in 1982 by the American National Standards Institute (ANSI)<sup>10</sup> as the guidelines which the FCC would use in its environmental processing procedures to evaluate human exposure to RF radiation. The Commission selected the non-government ANSI guidelines because they were scientifically based, widely accepted, and applicable to the general population as well as to workers.

The Commission stated that it would prefer to defer to the expert federal health and safety agencies for guidance in this area, but NEPA requires that environmental impact be evaluated regardless of whether federal standards currently exist or whether the FCC has the requisite expertise to set such standards. Therefore, in view of the lack of federal standards for exposure to RF radiation, the FCC chose to rely upon a recognized non-government standard. However, the Commission also recognized that other standard-setting organizations, including government agencies such as the Environmental Protection Agency (EPA), eventually may issue exposure guidelines in this area, and it is possible that different standards could be used by the FCC in the future.

By 1992, the 1982 ANSI standard had been superseded,<sup>11</sup> and no government agency had

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<sup>7</sup> Report and Order, General Docket 79-144, 50 Fed. Reg. 11151 (1985), 100 F.C.C. 2d 543 (1985).

<sup>8</sup> Further Notice of Proposed Rule Making, General Docket 79-144, 50 Fed. Reg. 10814 (1985), 100 F.C.C. 2d 568 (1985).

<sup>9</sup> Memorandum Opinion and Order, General Docket 79-144, 50 Fed. Reg. 38653 (1985).

<sup>10</sup> See reference 1.

<sup>11</sup> See reference 2.

issued an RF radiation exposure standard, so the Commission issued a Notice of Proposed Rule Making proposing "to amend and update the guidelines and methods used for evaluating the environmental effects of radiofrequency (RF) radiation from FCC regulated facilities."<sup>12</sup> In that Notice of Proposed Rule Making, the Commission stated: "Specifically, we are proposing to use the new standard for RF exposure recently adopted by the American National Standards Institute (ANSI) in association with the Institute of Electrical and Electronic Engineers, Inc. (IEEE), ANSI/IEEE C95.1-1992."

[Here add a paragraph relating to adoption of the proposal set forth in ET Docket 93-62.]

Under the FCC's NEPA rules, environmental concerns such as exposure to radiation are weighed and balanced in making a public interest determination as to the desirability of making a particular grant. If a facility or operation might result in human exposure in excess of the ANSI/IEEE limits, that facility or operation could constitute a "major action" as defined in the Rules. Environmental information would have to be provided by the applicant, and an environmental analysis would be required (see Part 1, Subpart I, of the Rules for a discussion of what information is required to be submitted in such a circumstance). However, an application can be amended to reduce or eliminate the possibility for excessive exposure. If an environmental impact statement were necessary, the 1992 ANSI/IEEE guidelines would be used in determining whether the environmental impact or risks outweigh the benefits of the proposal.

It should be emphasized that the process of compliance with the FCC's environmental rules is generally through a process of self-certification, and it is up to the applicant to make an initial determination as to whether a given facility or operation would be of potential environmental significance. If the applicant determines that the facility or operation would not have a significant effect on the environment, as defined in the Rules, then a simple indication of this conclusion, either at the appropriate place on an FCC form or by a written statement submitted with the application, is all that would be necessary. Once the determination has been made that a facility or operation would not have a significant environmental effect, no further environmental analysis is required.

#### The ANSI/IEEE Protection Guides for Exposure to RF Radiation

On September 26, 1991, the IEEE Standards Board approved "IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz", IEEE C95.1-1991. On November 18, 1992, the same standard was adopted by ANSI with the designation ANSI/IEEE C95.1-1992. The maximum permissible exposures (MPE) and maximum permissible induced and contact radiofrequency currents recommended by ANSI/IEEE are the guidelines that the FCC now has identified for use in evaluating environmental significance with respect to human exposure to RF radiation. Relevant sections of the ANSI/IEEE guidelines are reprinted in Appendix A. The following discussion summarizes the major features of the guidelines.

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<sup>12</sup> "Guidelines for Evaluating the Environmental Effects of Radiofrequency Radiation", Notice of Proposed Rule Making, ET Docket 93-62, 58 Fed. Reg. 19393 (1993).



The ANSI/IEEE guidelines incorporate frequency-dependent RF protection guides covering the electromagnetic frequency range from 3 kHz to 300 GHz. The guidelines are based on data showing that the human body absorbs RF energy at some frequencies more readily than at other frequencies. The most restrictive limits are recommended in the frequency range of 30-300 MHz where human absorption occurs at the highest rate. The least restrictive limits are recommended in the frequency range of 3 kHz to 3 MHz where human absorption is at the lowest rate. Except near the lower and upper limits of the frequency range, MPE for uncontrolled environments are lower than for controlled environments. With respect to the two-tier standard, the following is stated in the "Rationale" section of ANSI/IEEE C95.1-1992:

"To some, it would appear attractive and logical to apply a larger, or different, safety factor to arrive at a guide for the general public. Supportive arguments claim subgroups of greater sensitivity (infants, the aged, the ill and disabled), potentially greater exposure durations (24-hr/day, vs. 8-hr/day), adverse environmental conditions (excessive heat and/or humidity), voluntary vs. involuntary exposure, and psychological/emotional factors that can range from anxiety to ignorance. Non-thermal effects, such as efflux of calcium ions from brain tissues, are also mentioned as potential health hazards. The members of Subcommittee IV believe the recommended exposure levels should be safe for all, and submit as support for this conclusion the observation that no reliable scientific data exist indicating that:

- (1) Certain subgroups of the population are more at risk than others,
- (2) Exposure duration at ANSI C95.1-1982 levels is a significant risk,
- (3) Damage from exposure to electromagnetic fields is cumulative, or
- (4) Nonthermal (other than shock) or modulation-specific sequelae of exposure may be meaningfully related to human health.

"No verified reports exist of injury to human beings or of adverse effects on the health of human beings who have been exposed to electromagnetic fields within the limits of frequency and SAR specified by previous ANSI standards, including ANSI C95.1-1982. In the promulgation of revised guidelines, the responsibility of the current Subcommittee IV is adherence to the scientific base of data in the determination of exposure levels that will be safe not only for personnel in the working environment, but also for the public at large. The important distinction is not the population type, but the nature of the exposure environment. When exposure is in a controlled environment, the scientifically-derived exposure limits apply. When exposure is in an uncontrolled environment, however, an extra safety factor is applied under certain conditions; these include, but are not limited to, the following:

- (1) Exposure in the resonant frequency range, and
- (2) Low-frequency exposure to electric fields where exposure is penetrating or complicated by associated hazards like RF shocks or burns induced by metal contacts.

As defined earlier, uncontrolled environments include the domicile and most places where the infirm, the aged, and children are likely to be. It also includes the work environment where employees are not specifically involved in the operation or use of equipment that does or may radiate significant electromagnetic energy and where there

are no expectations that the exposure levels may exceed those shown in Table 2 [uncontrolled environments]. On the other hand, controlled environments may involve exposure of the general public as well as occupational personnel, *e.g.*, in passing through areas such as an observation platform near a transmitting tower where analyses show the exposure may be above that shown in Table 2 but is below that in Table 1 [controlled environments]. Other exposure conditions include that of the radio amateur who voluntarily and knowledgeably operates in a controlled RF environment."

To guard against the likelihood of excessive specific absorption rates (SAR) in tissues of the body, and particularly in the ankles, the 1992 ANSI/IEEE standard specifies maximum induced currents at frequencies of 100 MHz and below. Similarly, to avoid shock and/or burns, limits on contact currents are specified for the same frequency range. Induced current in a human is a function of electric field strength, body dimensions, grounding and footwear. Based on reference (3), it can be shown that, for controlled environments, compliance with the current standard is not likely if the spatially-averaged electric field strength does not exceed the MPE at frequencies of 0.45 MHz or less, does not exceed 45/f percent at frequencies from 0.45 to 3.00 MHz, and does not exceed 15 percent at frequencies in excess of 3.00 MHz. For uncontrolled environments, compliance with the current standard is not likely if the spatially-averaged electric field strength does not exceed the MPE at frequencies of 0.20 MHz or less, does not exceed 20/f percent of the MPE from 0.20 to 1.34 MHz, and does not exceed 15 percent of the MPE at frequencies above 1.34 MHz. (See also Section II.)

Contact currents depend strongly on the dimensions of the metallic object contacted as well as the frequency and strength of the ambient field. A long, vertical, metallic conductor immersed in even a moderate AM electric field can be a potential source of shocks and burns. Limited experimental data (see reference 4) indicates that objects of moderate size, such as a metal filing cabinet or car, will not produce contact currents in excess of the limits specified in the standard if the electric field is within the limits noted in the previous paragraph for avoiding excessive induced currents.

Maximum permitted exposure values in the standard are in terms of averages over an area equivalent to the vertical cross-section of the human body. (As will be shown in the measurements section, this may be approximated by taking measurements in a vertical line.) Exposure is further averaged over a time period with dependence on frequency. Frequency dependency permits the transition from exposure measured in minutes in the resonance range to seconds at frequencies approaching infra-red, reflecting the frequency-dependent change in the thermal time constant of the body. By limiting the averaging time at the higher frequencies, protection is provided to the decreasingly thin layers of skin and subcutaneous tissue penetrated as the frequency increases.

The standard excludes consideration of low-power devices except where the radiating structure is maintained within 2.5 cm (one inch) of the body. For body-worn devices, analyses must be made on the basis of avoiding the imposition of SARs in excess of the limits set by the standard. Low-power is defined for controlled environments as 7 watts or less at frequencies between 100 kHz and 450 MHz, and  $7(450/f)$  watts at frequencies between 450 and 1500 MHz. For uncontrolled environments, the limits are 1.4 watts at frequencies from 100 kHz to 450 MHz and  $1.4(450/f)$  watts for frequencies from 450 to 1500 MHz.

Since the ANSI/IEEE protection guides constitute exposure guidelines, they apply only to

locations that are accessible to workers and the public. Such access can be restricted or controlled by the use of fences, warning signs, and other appropriate measures. In the case of exposures in controlled environments, procedures can be instituted for working in the vicinity of RF sources that will prevent excessive exposure of personnel. Examples of such procedures would be restricting the time an individual could be near an RF transmitter or requiring that work on such transmitters be performed only while the transmitter is turned off or while power is appropriately reduced. The use of auxiliary transmitters could prevent excessive exposure of personnel at the main transmitter site during maintenance activities. Section IV of this bulletin should be consulted for further information on controlling exposure.

Because of the exclusion clauses (Sections 4.2.1.1 and 4.2.2.1) of the ANSI/IEEE guidelines, use of a radiofrequency device between 100 kHz and 1.5 GHz with an input power no greater than the limits specified would not, by definition, violate the guidelines. Therefore, the granting of a license or permit by the FCC for the operation of such a device would not be a "major action" and would be excluded automatically for consideration under the FCC's environmental processing procedures. This exclusion would apply as long as the FCC uses the ANSI/IEEE protection guides as its processing guidelines, or unless the Commission decided on its own motion to prepare an environmental impact statement in some particular case.

The ANSI/IEEE protection guides are defined in terms of power density, electric field strength and magnetic field strength. In the far-field of an antenna, where the electric field vector (E), the magnetic field vector (H), and the direction of propagation can be considered to be all mutually orthogonal, these quantities are related by the equation:

$$S = E^2/3770 = 37.7 H^2$$

where: S = power density in milliwatts per square centimeter (mW/cm<sup>2</sup>)  
E = electric field strength in volts/meter (V/m)  
H = magnetic field strength in amperes/meter (A/m)

In the near-field of a transmitting antenna, the term "far-field equivalent" or "plane-wave equivalent" power density is used often to indicate a quantity calculated by using the near-field values of E<sup>2</sup> or H<sup>2</sup> as if they were obtained in the far-field. However, ANSI/IEEE specifies that for near-field exposures, the only applicable protection guides are the electric and magnetic field strengths, respectively. Therefore, the values of plane-wave equivalent power density are given only for reference purposes in those cases. At frequencies in excess of 300 MHz, virtually all exposures are in the far-field; hence, ANSI/IEEE specifies only power density above 300 MHz. Power density is usually expressed in units of milliwatts per square centimeter (mW/cm<sup>2</sup>) or microwatts per square centimeter (μW/cm<sup>2</sup>).

The ANSI/IEEE guidelines apply to exposure regardless of the RF source. Therefore, in mixed or broadband fields, where a number of different frequencies are involved, the contributions of all RF sources must be considered. However, where multiple transmitters are involved, sources that contribute no more than one percent of the applicable maximum permissible exposure may be excluded as being inconsequential. When different limits are recommended for different frequencies, the fraction of the limit incurred within each frequency interval should be determined, and the sum of all such fractions (greater than 1/100) should not exceed 1.0.

## Section II: PREDICTION METHODS

### Introduction

The material in this section is designed to provide assistance in determining whether a given facility would be in compliance with guidelines for human exposure to RF radiation. The calculation methods discussed below may be helpful in evaluating a particular exposure situation. However, applicants for broadcast stations should first consult the relevant subsection below, dealing with FM radio, television, or AM radio stations. Many broadcast applicants will be able to determine that a given facility would be in compliance, with regard to exposure in either controlled or uncontrolled environments, simply by consulting the tables and figures discussed in these subsections. With regard to particular occupational exposures in either controlled or uncontrolled environments, Section IV of this bulletin should be consulted.

Applicants for facilities utilizing aperture antennas should first consult the subsection below which deals with those types of antennas. For a discussion of the ANSI/IEEE guidelines and such concepts as power density, refer to Section I of this bulletin.

### Calculations

Calculations can be made to predict radiation levels around typical RF sources. For example, for the case of an isolated antenna, a "worst-case" prediction for power density, electric and magnetic fields in the far-field of the antenna can be made by use of the following equations (for typical units see examples below):

$$\text{or: } S = PG/4\pi R^2 \quad (1)$$

$$S = EIRP/4\pi R^2 \quad (2)$$

$$E = [(3770)(S)]^{1/2} \quad (3)$$

$$H = (S/37.7)^{1/2} \quad (4)$$

where:  $S$  = power density in milliwatts per square centimeter (mW/cm<sup>2</sup>)

$P$  = power input to the antenna in milliwatts (mW)

$G$  = gain of the antenna relative to an isotropic radiator

$R$  = distance to the center of radiation in centimeters (cm)

$EIRP$  = equivalent (or effective) isotropic radiated power in mW

$E$  = electric field strength in volts per meter (V/m)

$H$  = magnetic field strength in amperes per meter (A/m)

For a truly worst-case approximation, 100% ground reflection should be assumed, resulting in a potential doubling of predicted field strength (either electric or magnetic) and a four-fold increase in (far-field equivalent) power density. The equations for power density, electric and magnetic field

strength then become:

$$S = PG/\pi R^2 = EIRP/\pi R^2 \quad (5)$$

$$E = 2[(3770)(S)]^{1/2} \quad (6)$$

$$H = 2(S/37.7)^{1/2} \quad (7)$$

However, in the case of FM and TV broadcast antennas, the Environmental Protection Agency recommends a more realistic approximation for ground reflection (see Reference 5) by assuming a maximum 1.6-fold increase in fields strength or an increase in power density of 2.56 (1.6<sup>2</sup>). Equations (2), (3) and (4) then become:

$$S = (2.56)EIRP/4\pi R^2 = (0.64)EIRP/\pi R^2 \quad (8)$$

$$E = 1.6[(3770)(S)]^{1/2} \quad (9)$$

$$H = 1.6(S/37.7)^{1/2} \quad (10)$$

Although generally applicable in the far-field of a transmitting antenna, equations (5) and (8) may be used also to estimate a "worst-case" upper limit for "far-field equivalent" power densities<sup>13</sup> in the near-field of the antenna.

If the values calculated by use of equations (5), (6) and (7), or (8), (9), and (10) do not exceed the recommended exposure level, for the appropriate environmental classification, in accessible areas, then the facility in question normally would be in compliance with the RF protection guidelines. If the calculated value exceeds the recommended exposure level in accessible areas, a more extensive and detailed analysis would be required. The tables and figures provided in the Appendices of this bulletin are designed to facilitate such an analysis for broadcast facilities.

An example of the use of the above equations follows. An FM broadcast station is transmitting with a nominal effective radiated power (ERP) of 100 kilowatts (horizontal polarization) and is using a circularly polarized antenna. The height to the center of radiation is 100 meters (328 feet) above ground. Using formulas (8), (9) and (10) above, what would be the calculated worst-case power density, electric field and magnetic field at ground level 20 meters from the base of the broadcast tower?

From simple trigonometry it can be shown that R would be about 102 meters  $(100^2 + 20^2)^{1/2}$  or 10,200 centimeters. Since FCC ERPs are referenced to a half-wave dipole, it is necessary to multiply the total ERP by 1.64 (the gain of a half-wave dipole relative to an isotropic radiator) in order to obtain EIRP. Also, in this case, since the antenna is "circularly polarized", the total power used in the calculation must include power both in the horizontal and in the vertical polarizations (see discussion in following subsection). Therefore, assuming 100 kilowatts in the vertical polarization, the calculations become:

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<sup>13</sup> See discussion of "far-field equivalent" power density in Section I.

$$S = \frac{(0.64)(1.64)(200,000 \text{ watts})(1000 \text{ milliwatts per watt})}{\pi(10,200 \text{ cm})^2}$$

$$= \text{about } 0.64 \text{ mW/cm}^2$$

$$E = 1.6[(3770)(0.64)]^{1/2} = 79 \text{ V/m}$$

$$H = 1.6(0.64/37.7)^{1/2} = 0.21 \text{ A/m}$$

Although the above equations may be used for estimating worst-case upper limits, it is often desirable to obtain more reasonable and accurate estimates. The following sections of this bulletin provide guidelines and assistance for analyzing specific types of RF transmitting facilities.

### FM Broadcast Stations

The Environmental Protection Agency (EPA) has developed a computer model for estimating power densities in the vicinity of typical FM broadcast stations. In arriving at its predictions the EPA considers the following variables of the station: (1) effective radiated power, (2) height above ground of the center of radiation, (3) polarization of the transmitted signal, (4) type of antenna, and (5) number of elements (bays) in the antenna array. The EPA model is discussed in detail in an EPA publication by P. Gailey and R. Tell (Reference 5).

FM broadcast antennas normally consist of arrays up to 16 elements (or bays) stacked vertically, and typically side-mounted, on a tower. The elements are usually spaced about one wavelength apart and are fed approximately in phase with power distributed equally among the elements. The relative field strength patterns used in the EPA model are the product of the element and array patterns,

The model has been used to calculate expected field strengths on the ground near FM broadcast towers using the element and array patterns. Ground reflection has been taken into account in these calculations. A number of assumptions were made in the development of the EPA model, and there can be no guarantee of its accuracy. However, measurements made by EPA around specific broadcast installations have shown good agreement with values predicted by the model, indicating that the model offers a reasonable approach for predicting the upper bounds of field strength near these towers. The FM stations studied represented a variety of antenna types, powers, and terrains. In all cases, the highest values predicted by the model were not exceeded by the measurements.

The model predicts fields (expressed in units of "plane-wave equivalent" or "far-field equivalent" power density) at ground level near typical broadcast towers using various antenna types and specific values for ERP, tower height, and number of elements (bays). Conversely, the model can be used to predict the minimum tower heights necessary to prevent fields from exceeding an established level, such as the limits recommended by ANSI/IEEE for the FM frequency band. The predictions apply to fields from 0 to 2 meters above the ground.

Total ERP is used by the model in its calculations. This means that the total ERP would be

the sum of the horizontal ERP and the vertical ERP. For example, a 100-kW FM station using a circularly polarized antenna would be assumed to have a total ERP of 200 kW (100 + 100) unless otherwise specified. Alternatively, a station may have different values of ERP for the horizontal and vertical polarizations, e.g., 100 kW horizontal, and 75 kW, vertical, would mean a total ERP of 175 kW. It should be emphasized that total ERP must be used when consulting the tables and figures in Appendix B, discussed below.

Appendix B contains tables derived from the EPA computer model. Table 1 in Appendix B gives estimates of antenna heights necessary to prevent ground-level power density from exceeding the ANSI/IEEE FM band recommended limit of 1.0 mW/cm<sup>2</sup> for controlled environments and 0.2 mW/cm<sup>2</sup> for uncontrolled environments. This table should be consulted as the first step in an evaluation of a given FM facility to determine whether it would comply with the ANSI/IEEE guidelines. Note that the table gives predicted minimum antenna heights for a number of combinations of total ERP and number of bays. For each entry in the table two values are given. The top (higher) number represents the "worst" case, in which the calculations were based on the use of dipole elements in the array. The bottom (lower) number represents the "best" case achievable, according to EPA's analysis, using available antennas (with one wavelength element spacing) designed to minimize downward radiation.

Values for worst-case antennas (dipole elements) are independent of the number of bays due to the fact that vertical radiation patterns from horizontal dipole elements are circular, and the location of the peak field will always be at the tower base directly below the antenna. For antennas with other types of elements this is not necessarily true, and peak fields may be at locations other than directly below the antenna.

The values on Table 1 apply to single FM antennas and to towers whose bases are at about the same level or higher than the surrounding terrain. However, for multiple antennas on the same tower, a worst-case estimate could be made using this table by assuming that the total ERP from all antennas was concentrated at the center of radiation of the antenna that is the lowest on the tower. For such an imaginary transmitting source, the number of bays could be considered to be that of the antenna with the smallest number of bays. Where the sum of the ERPs exceeds 200 kW, the maximum ERP included in the table, the number in the table may be increased by a factor equal to the square root of the power ratio. For example, assume three antennas of good current design, each radiating 100 kW, circularly polarized, and the least number of bays of any of the antennas is four. For a controlled environment, the minimum height for 200 kW, four bays, is 23.90 meters. Then for the example used, the minimum height becomes:  $(23.90)(600/200)^{1/2} = (23.90)(1.732) = 41.40$  meters.

In some cases, particularly when an antenna has a relatively large number of bays, the lowest element may be a significant distance below the center of radiation. Therefore, in these situations a conservative estimate for minimum antenna height could be made by considering the values in Table 1 to correspond to the distance from the lowest element to ground.

For combinations of ERP/bays intermediate to those listed in Table 1, interpolation can be used between entries in the table, assuming a direct relation between antenna height and power and an inverse relation between antenna height and number of bays. Alternatively, the next highest value could be used for ERP and the next lowest value could be used for number of bays. For example, a station having a total ERP of 20 kW and 5 bays could use the values given in the table for 25 kW and 4 bays (28.90 meters, worst case for the controlled environment, or 8.40 meters, best case for the

controlled environment), since these values would be conservative. Interpolation would yield more realistic values of 25.37 meters for worst case (controlled environment), regardless of number of bays, and, for best case, 6.93 meters (controlled environment).

For a given FM facility, Table 1 may be used to demonstrate that a station is already in compliance with the ANSI/IEEE guidelines. However, if the values listed in Table 1 indicate that the antenna's center of radiation is less than the minimum tower height necessary for compliance, then Figures 1-8 in Appendix B should be consulted. These figures were generated by the EPA's computer-based model for FM broadcast towers. They contain curves of far-field equivalent power density versus distance from the tower base on the ground for various combinations of total ERP, tower height, and number of bays. By consulting the appropriate figure, the extent of a given exposure level on the ground can be predicted. Thereby determining where access should be restricted (see Section IV on controlling exposure to RF fields). At FM broadcast frequencies below 100 MHz, electric field maximum permissible exposure (MPE) is more restrictive than magnetic field MPE in terms of far-field equivalent power density. Therefore, using as the criterion  $1 \text{ mW/cm}^2$  ( $1000 \text{ } \mu\text{W/cm}^2$ ) for controlled environments and  $0.2 \text{ mW/cm}^2$  ( $200 \text{ } \mu\text{W/cm}^2$ ) for uncontrolled environments assures compliance with both electric and magnetic field MPE. It should be emphasized that Figures 1-8 show "worst-case" curves assuming dipole elements, and distances indicated in these figures should be conservative. Different curves would be obtained if other element types were assumed. Furthermore, if the relative field factor for the full range of vertical plane angles is known for the antenna to be used, a more realistic determination of exposure can be made by the method described later in this section.

The following example will illustrate appropriate use of Figures 1-8. In this example it is desired to define the area around the base of an FM broadcast tower where power densities would be predicted to be in excess of the ANSI/IEEE guidelines. This hypothetical station transmits using a 4-bay antenna and has a total ERP of 200 kW (H+V). The height to the center of radiation is approximately 62 meters which can be rounded to 60 meters for purposes of using the appropriate figure in Appendix B. Figure 6 in Appendix B shows prediction curves for an antenna height (ground to center of radiation) of 60 meters. The equivalent power density is given in terms of power density per kilowatt total ERP. From this figure it can be determined that, for a 4-bay, 200 kW station with a height to the radiation center of 60 meters, the model predicts that the ANSI/IEEE limit in the FM band of  $1 \text{ mW/cm}^2$  in a controlled environment, equivalent to  $1000 \text{ } \mu\text{W/cm}^2$ , would extend 28 meters from the base of the tower in the worst case. Therefore, a fence or other appropriate restrictive barrier could be placed at this distance to prevent access to the area where levels in excess of the ANSI/IEEE limit could be present.

This distance was obtained by the following procedure:

- (1) Divide  $1000 \text{ } \mu\text{W/cm}^2$  by the total ERP of 200 kW to obtain  $5 \text{ } \mu\text{W/cm}^2/\text{kW}$  (power density per kW total ERP).
- (2) Find  $5 \text{ } \mu\text{W/cm}^2/\text{kW}$  on the vertical axis of Figure 6.
- (3) Find the point on the 4-bay curve corresponding to  $5 \text{ } \mu\text{W/cm}^2/\text{kW}$  and locate the predicted distance (about 28 m) given on the horizontal axis.

These figures can be used to predict exposure to the permissible uncontrolled environment



level ( $200 \mu\text{W}/\text{cm}^2$ ), or any other desired level, by dividing that desired level by the total ERP in step (1) above. For example, if the desired level is  $200 \mu\text{W}/\text{cm}^2$ , the vertical axis figure is  $1 \mu\text{W}/\text{cm}^2$  from step (1), and the predicted distance for the 4-bay antenna, 60 meters above ground level is approximately 41 meters.

For cases in which an FM tower is mounted on a building, or when the location of concern is not on the ground, e.g., exposure in a nearby building or other structure, Table 1 should not be used. In these cases the field strength levels in the main beam of an antenna are more relevant to an environmental analysis. Figures 9a and 9b in Appendix B give minimum distances in the main beam from single FM antennas required for compliance with the ANSI/IEEE recommended limits for controlled and uncontrolled environments. Only one set of values is given in each figure since, for main-beam exposure, the type of antenna element does not alter the results. Figure 9b should be used in situations where an FM antenna might be responsible for irradiating a nearby building or other occupied structure of comparable height. Reference 6 contains data on actual measurements, made by EPA, of RF field strength in buildings near broadcast antennas.

If the height of the irradiated building or structure is less than the center of radiation, the main-beam distances given in Figure 9b would likely be overly predictive, i.e., greater than necessary for compliance. In such case, a relative field factor, based on the antenna's vertical plane radiation pattern, could be taken into account to give a more realistic estimate. This could be accomplished by multiplying the antenna's total ERP by the square of the relative field factor for the depression angle of interest. The resulting value could then be applied to the horizontal axis of Figure 9b in order to determine the minimum line of sight distance from the antenna center of radiation required for compliance.

### Television Broadcast Stations

Antennas used for television broadcasting are similar to FM antennas in that they usually consist of an array of radiating elements mounted on a tower. However, the elements used for TV antennas are generally of a more complex design and radiate less energy toward the ground than FM systems. Also, television broadcast antennas are typically mounted on higher towers than FM antennas, which further reduces ground-level radiation.

The EPA's computer model has not been applied to television broadcast antennas due to the unavailability of complete vertical radiation patterns for television antennas. However, EPA developed an alternative approach for the analysis of television antenna systems based on available information. Results of the alternative EPA approach had been based on the 1982 ANSI standard, and are equally applicable to the controlled environment guidelines of the ANSI/IEEE 1992 standard. By applying appropriate multiplying factors, the data have been extended to the uncontrolled environment guidelines.

For VHF-TV antennas, EPA found that the most commonly used type of radiating element to be the "batwing." Therefore, for convenience, the assumption was made that all VHF-TV elements are of the batwing design. Data obtained by EPA indicated that batwing elements may radiate approximately 20% as much in the downward direction as in the main beam in terms of relative field strength, i.e., the relative field factor in the downward direction is approximately 0.20. Although,

since the EPA made its study, other antenna types have been favored for new, or modified VHF-TV stations, particularly in the high band of Channels 7 through 13, the EPA work remains valid with some tendency to over estimate downward radiation.

Although detailed modeling was not possible, EPA used typical values of relative field strength directly beneath the antenna, i.e., the shortest distance to ground, to arrive at a prediction method for ground-level field strength due to VHF-TV antenna systems. For directions other than straight down, greater distances from the antenna would be involved, resulting in lower predicted field strengths at ground level. The following equation was used by EPA to predict fields at the base of TV broadcast towers:

$$S = \frac{(2.56)(1.64)(100)(F^2)[(0.4)(\text{VERP}) + \text{AERP}]}{4\pi D^2} \quad (11)$$

Where:

S = highest power density in microwatts/sq. cm. ( $\mu\text{W}/\text{cm}^2$ ) predicted at ground level

VERP = total peak visual ERP in watts

AERP = aural ERP in watts

F = typical relative field factor in the downward direction (-60 to -90 degrees elevation)

D = distance from ground to center of radiation in meters.

In the above equation, 1.64 is the gain of a half-wave dipole relative to an isotropic radiator. The factor of 2.56 reflects the potential maximum increase in power density due to ground reflection assuming a field reflection coefficient of 1.6 [ $(1.6)^2 = 2.56$ ]. The factor of 0.4 converts peak visual ERP to an RMS value which is more realistic with regard to practical conditions for video transmission. The factor of 100 is necessary for conversion to appropriate units of power density.

The values for ERP in the above equation are total ERP. Therefore, although most television antennas transmit horizontally polarized signals only, if a circularly-polarized, or elliptically-polarized, antenna is used, the contributions from both horizontal and vertical polarizations must be included.

If the relative field factor, F, is known, equation (11) could be used to make a more accurate prediction. However, if F is not known, a value of 1.0 could be assumed as a worst-case approximation. As explained above, EPA assumed that a typical level of radiation directly downward from batwing-type antennas was 20% of the level in the main beam. Therefore, in such a case, the relative field factor, F, directly below the antenna would be 0.2. Antennas of recent manufacture are likely to have a relative field factor, F, less than 0.2 directly downward.

The following variation of equation (11) can be used to predict the minimum antenna height necessary to bring a television stations below a given power density level anywhere on the ground.

$$MAH = \sqrt{\left( \frac{(2.56)(1.64)(F^2)(100)[(0.4)(VERP) + AERP]}{4\pi S} \right)} \quad (12)$$

Where: MAH = minimum antenna height (ground to center of radiation) necessary to reduce the ground-level RF fields below a given power density, S, [units same as in equation (11)].

Equations (11) and (12) can be used for both VHF and UHF television antennas. However, for UHF antennas, EPA used different typical values of F, the relative field factor, in the downward direction. Although EPA was not able to obtain the required values of F from the manufacturers' literature, an alternative prediction method was developed based on field data and discussions with a major UHF antenna manufacturer. The manufacturer's engineers stated that typical values of F for UHF antennas are about 10%, and some antennas have an F of about 5% for downward radiation. These values agreed well with measurements made by EPA in field studies beneath UHF antennas.

Smaller F values are to be expected from UHF antennas than from VHF antennas. UHF antennas have very high gain in the main beam which means that a high proportion of the transmitted energy is concentrated there rather than radiated downward or in other directions.

Compliance with the ANSI/IEEE guidelines is somewhat more complicated in the case of UHF-TV facilities. Except for magnetic field strengths below 100 MHz, the ANSI/IEEE guidelines are uniform in the VHF band. As to the lower frequency magnetic field requirements, they are less restrictive than for electric fields. Therefore, the uniform electric field guidelines are likely to be the factor determining compliance with exposure specifications. Throughout the entire UHF band, the guidelines, specified only in terms of power density, are frequency dependent (see Appendix A). For example, the protection guide recommended for Channel 14 (center frequency = 473 MHz) is 1.58 mW/cm<sup>2</sup> for controlled environments and 0.32 mW/cm<sup>2</sup> for uncontrolled environments, while that recommended for Channel 69 (center frequency = 803 MHz) is 2.68 mW/cm<sup>2</sup> for controlled environments and 0.54 mW/cm<sup>2</sup> for uncontrolled environments.

Equation (11) was used to prepare Tables 1-4 in Appendix C. These tables show minimum "worst-case" distances from single VHF or UHF television antennas required for compliance with ANSI/IEEE C95.1-1992 exposure guidelines. Table 1 gives predicted minimum distances from VHF-TV antennas for various combinations of visual and aural power. Tables 2, 3, and 4 list the ANSI/IEEE limits for the various UHF-TV channels assuming three different values for aural power: 10%, 15%, or 22% (the maximum allowed under the FCC's Rules), respectively. For intermediate values of visual and/or aural power, an applicant may interpolate between values given in the tables, or, alternatively, use the value given for the next highest level of visual and/or aural power. As with FM stations, total ERP must be used.

When F, the relative field factor is known, equation (12) could be used to calculate minimum antenna height for compliance. However, if F is not known, then it would be best to use the values

given in the tables, which assume a value of 1.0 (main beam) for F. Using the tables for estimating minimum antenna height is especially recommended in cases where the supporting tower is relatively short and there may be a greater contribution to ground-level field strength from the lower antenna elements.

In addition to determining minimum antenna heights, Tables 1-4 may be used to estimate minimum distances in the main beam of television antennas necessary for compliance with the ANSI/IEEE limits. As with FM radio stations, such an analysis might be necessary when nearby occupied structures are in the path of the main beam.

### AM Broadcast Stations

Unlike the 1982 ANSI standard, which specified magnetic field exposures equal to electric field exposures in terms of far field equivalent power density, the 1992 ANSI/IEEE standard recognizes an important difference between the two exposures at AM broadcast frequencies. Electric field exposure must be limited to avoid shock and burn effects. Such considerations do not apply to magnetic field exposures. Furthermore, energy absorption by the body at AM broadcast frequencies is very low. Accordingly, ANSI/IEEE C95.1-1992 allows magnetic field exposures far in excess of electric field exposures as related to far field equivalent power density. The consequence is that the minimum distance from an AM radiator satisfying the maximum permissible exposure standards of the 1992 guidelines is governed entirely by the magnitude of the electric field strength.

The ANSI/IEEE guideline for maximum permissible exposure to electric fields is uniform throughout the entire AM broadcast band for controlled environments. For uncontrolled environments, the maximum permissible exposure to electric fields is the same as for controlled environments to a frequency of 1340 kHz, but falls below the controlled environment limits above 1340 kHz (1.34 MHz). For uncontrolled environments, the maximum permissible exposure to electric fields at frequencies above 1340 kHz, is determined by the ratio  $823.8/f$ , where  $f$  is in MHz.

EPA, using the Numerical Electromagnetics Code (NEC) developed for linear antennas by the Lawrence Livermore National Laboratory, calculated the near-field electric and magnetic signal strengths for a number of antenna heights. The EPA calculations have formed the basis for tables and graphs shown herein. Limitations inherent to the NEC for very close-in near-field calculations are believed to cause overprediction of the distances at which various field levels may be exceeded. However, as described later, both theoretical calculations and actual measurements can provide guidance on the extent that compliance with the 1992 ANSI/IEEE standard can be achieved for workers in actual contact with an energized AM broadcast tower.

Because of the relatively long wavelengths used for AM broadcasting, excessive human exposures occur only in the near-field of the antenna. Therefore, the relevant quantities to be evaluated are the electric and magnetic field strengths. As noted above, the disparity between the exposure standards for electric and magnetic field strengths results in the electric field strength being, by far, the more critical of the two parameters.

Table 1 in Appendix D shows worst-case distances from single AM broadcast towers where various electric field strength levels are predicted to occur. Table 1A shows worst-case minimum

distances required to avoid exceeding the electric field maximum permitted by ANSI/IEEE within the AM broadcast band for uncontrolled environments. Since the maximum permissible exposures are identical for controlled and uncontrolled environments over the frequency range from 540 through 1340 kHz, the first line in Table 1A is equally applicable to both environmental categories, and the distances in that line can be seen to be the same as the distances specified for 614 V/m in Table 1.

Tables 1 and 1A apply to any frequency or electrical height. In some cases, these values may overestimate the distances assuring not exceeding the indicated field strengths, but in no case should they underestimate such distances.

The model computes field strength values in the vicinity of single tower stations. However, for multiple-tower arrays, a "worst-case" prediction could be made that all transmitted power is radiated from each tower. Therefore, in such cases, the values in Tables 1 and 1A could be used to define a zone of restriction around the array, consisting of circles with equal radii, each of which could be centered around a tower in the array. Alternatively, if the power distribution among the several towers in an array is known, Tables 1 and 1A may be used with the individual powers to determine radii applicable to those towers. When the same towers are used in alternative modes, such as in the case of different patterns day and night, the highest power input to each tower must be used. In an unusually short-spaced array, field strength from adjacent towers may have to be considered, but in the usual system, where tower spacings are no less than approximately 70 electrical degrees, the towers can be treated as if they were standing alone.

In addition to Tables 1 and 1A, Figures 1-3 of Appendix D can be used to predict field strengths around typical AM broadcast towers. The curves in these figures were generated using the NEC model applied to these radiators. The figures give worst-case predicted electric and magnetic field strength values versus distance for towers with electrical heights equal to 0.1, 0.25, and 0.5 wavelengths, respectively. Since the field strength predictions will vary with frequency, only the "worst-case frequency" curves are shown. These curves may be overly conservative in some cases, but, regardless of frequency, actual values should be lower than these predictions.

Figures 1-3 give predictions for a station transmitting at 1 kilowatt. For predictions of field strength at other power levels, the values obtained from Figures 1-3 should be multiplied by the square root of the power. An example will illustrate.

Suppose a 50-kilowatt station is located adjacent to a publicly accessible area. An estimate is desired of the field strength levels expected in this area at a distance of 50 meters from the station's tower. Assume a 0.25 wavelength tower. Then, from Figure 2 the predicted electric field strength (for 1 kilowatt) would be about 5 volts/meter, and the predicted magnetic field strength would be about 0.015 amperes/meter. Multiplying these numbers by the square root of 50 (7.07) yields predicted values of approximately 35 V/m and 0.11 A/m, both values well below the ANSI/IEEE guidelines for the AM band. (As noted later herein, electric field strength of this magnitude will also satisfy the induced current requirements of the standard.)

## Aperture Antennas

Aperture antennas include those used for such applications as satellite earth stations, point-to-point microwave radio, studio-transmitter links, television remote pickup, and various types of radar. Generally, these types of antennas have parabolic surfaces and many have circular cross sections. They are characterized by their high gain resulting in the transmission of power in a well-defined, collimated beam with little angular divergence. Systems using aperture antennas operate at microwave frequencies, *i.e.*, generally above 1 GHz.

Those systems involved in telecommunications operate with power levels that depend on the distances over which communications are to be transmitted and the number of channels required. Almost all have circular cross sections. The important characteristic, antenna diameter, is determined generally by the requirements for reception. With regard to some operations, such as earth-satellite transmitting antennas, the combination of high transmitter power and large antenna diameters produce regions of significant power density that may extend over relatively large distances in the main beam. Many "dish" antennas used for earth-satellite transmissions utilize the Cassegrain design in which power is fed to the antenna from a primary source located at the center of the parabolic reflector. Radiation from this source is then incident on a small hyperbolic subreflector located between the power feed and the focal point of the antenna, and is then reflected back to the main reflector resulting in the transmission of a collimated beam.

Because of the highly directional nature of these and other aperture antennas, the possibility of significant human exposure to RF radiation is considerably reduced. The power densities existing at locations where people may be exposed is substantially less than on-axis power densities. Factors that have to be taken into account in assessing the potential for exposure are main-beam orientation, antenna height above ground, power delivered to the antenna, antenna size, location relative to where people live or work, and the operational procedures followed at the facility.

Earth-satellite uplink stations have been studied analytically and by measurement to determine methods to estimate potential environmental exposure levels. An empirical model has been developed, based on antenna theory and measurements, to evaluate potential environmental exposure from these systems (Reference 7).

In general, for parabolic aperture antennas with circular cross sections, the following information can be used in evaluating a specific system for potential environmental exposure. In the near-field, or Fresnel region, of the main beam, the power density can be at a maximum before it begins to decrease with distance. The extent of the near-field can be described by the equation:

$$R = \frac{D^2}{4\lambda} \quad (1)$$

where: R = extent of near-field  
D = antenna diameter  
 $\lambda$  = wavelength

The magnitude of the on-axis (main beam) power density varies according to location in the near-field. However, the maximum value of the near-field on-axis power density is given by the equation:

$$S = \frac{16\eta P}{\pi D^2} \quad (2)$$

where: S = maximum near-field power density  
 $\eta$  = aperture efficiency, typically 0.5-0.75  
P = power fed to the antenna  
D = antenna diameter

Power density in the transition region decreases inversely with distance from the antenna, while power density in the far-field (Fraunhofer region) decreases inversely as the square of the distance. For purposes of evaluating potential exposure, the distance to the beginning of the far-field region can be expressed by the equation:

$$R = \frac{0.6D^2}{\lambda} \quad (3)$$

where: R = distance to beginning of far-field  
D = antenna diameter  
 $\lambda$  = wavelength

On-axis power densities in the transition region and in the far-field of an aperture antenna can be estimated by use of the following equations:

transition region:

$$S = \frac{S(nf)R(nf)}{R} \quad (4)$$

where: S = power density  
S(nf) = maximum power density for near-field calculated using (2) above  
R(nf) = extent of near field calculated using (1) above  
R = distance to point of interest

far-field

$$S = \frac{PG}{4\pi R^2} \quad (5)$$

where: S = power density (on axis)  
P = power fed to the antenna  
G = gain of the antenna relative to an isotropic antenna  
R = distance to the point of interest

In the far-field region, power is distributed in a series of maxima and minima as a function of the off-axis angle (defined by the antenna axis, the center of the antenna and the specific point of

interest). For constant phase, or uniform illumination, over the aperture the main beam will be the location of the greatest of these maxima. The on-axis power densities calculated from the above formulas represent the maximum exposure levels that the system can produce. Off-axis power densities will be considerably less. Estimated exposure levels have been calculated for many satellite communications systems operating at normal powers. A comparison of measured and predicted values is given in Reference 8.

For off-axis calculations in the near-field and in the transition region, it can be assumed that, if the point of interest is at least one antenna diameter removed from the center of the main beam, the power density at that point would be at least a factor of 100 (20 dB) less than the value calculated for the equivalent distance in the main beam (see Reference 7 for data). For off-axis calculations in the far-field, the calculated main-beam power density obtained by use of equation (5) above can be multiplied by the appropriate relative power density factor obtained from the antenna gain pattern to obtain a more realistic estimate.

#### Compliance with Induced and Contact Current Limits

ANSI/IEEE C95.1-1992, for the first time, imposes limits on induced and contact body currents in order to assure not exceeding the SAR limits that provide the basis for the designated MPEs. Although the 1992 ANSI/IEEE standard contains the following statement: "Evaluation of the magnitude of induced currents will normally require a direct measurement."<sup>14</sup>, substantial work has been done both with anatomically-based models and by actual measurements (References 3 and 9 through 14) that thresholds of electric field strength can be established below which the measurement of induced currents need not be undertaken. The electric field strength values can be derived either by calculation, as described herein, or by measurements as described in Section III.

Appendix E provides a table and graphs, derived from the references, to be used in determinations of the likelihood of exceeding the current standards once electric field strengths have been determined. Magnetic fields contribute very little to induced currents and may be ignored (Reference 10). Except for measured currents in tower climbers on energized AM towers (Reference 14), the data are for barefooted adults standing erect in a vertically-polarized field. As a result, the data shown are likely to overstate the current to be expected in practice where individuals could be expected to be wearing some sort of footgear. Measurement data (Reference 9) show that any type of shoe will reduce the current substantially. Additionally, although all data used are based on the total current through both feet well grounded, the limits specified are on the basis of the maximum permitted current through one foot. Therefore, every location where the electric field strength is found to be in excess of the limits shown in Appendix E will not necessarily produce currents in excess of the standards. Footwear, poor grounding, or the dominance of horizontally-polarized fields will all serve to mitigate induced current magnitude.

Table 1 and Figure 1 in Appendix E provide the relationship of induced current to electric field strength for an erect adult. (Since height is far more important than mass in affecting the magnitude of the induced current, children are automatically protected if the criterion is limiting current in the adult.) Table 1 includes also tabulations of electric field strength assuring compliance

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<sup>14</sup> Section 4.1.1(a)(ii).



with the current limits for controlled and uncontrolled environments. Figures 2 through 5 show the same data in graphic form. Figures 3 and 5 are expansions of portions of the graphs in Figures 2 and 4.

A particular problem in AM stations is the need to do work on towers with least disruption to station operation. Tower work during nighttime hours is more hazardous than during the daytime, so, whenever possible, such work should be accomplished during daylight hours. Reference 13 is an analytical study relating energy absorption rate, in a tower climber, to power input for a range of frequencies and tower heights. Reference 14, containing actual current measurements made on energized AM towers confirms that the radial electric field strength is the appropriate reference parameter and that the theoretically derived data of Reference 13 are conservative in that they tend to overstate the body current of the climber. Figure 6 in Appendix E reduces the data of Reference 13 to graphic form providing permissible power levels assuring that the exposure of the tower climber remains within the limits of the standard.

Caution is necessary in any attempt to work on energized AM towers even at reduced power levels. The voltage across the base insulator would still be great enough to produce a burn if the worker contacts the tower while standing on the ground. Access to the tower above the base insulator must be by the use of a dry wooden ladder or other nonconducting device. Contact with guy wires must be avoided also. A substantial voltage difference can be found between the tower and the top section of a guy beyond the uppermost insulator which is likely to be close to the tower. The use of insulating gloves and shoes will further reduce induced and contact currents in the worker.

### Section III: MEASURING THE RF ENVIRONMENT

#### Reference Material

In some cases the prediction methods described cannot be used, and actual measurements of the RF field may be necessary to determine whether there is a potential for human exposures in excess of the specified guidelines. For example, in a situation such as a *de facto* antenna farm with multiple users the models previously discussed would generally not be applicable. Measurements may be desired also for predictions that are slightly greater or slightly less than the threshold for excessive exposure, or when fields are likely to be distorted seriously by objects in the field, e.g., conductive structures.

Techniques have been described and instrumentation is available for measuring the RF environment near broadcast and other transmitting sources. Several references are available which provide detailed information on measurement procedures, instrumentation, and potential problems.

"ANSI/IEEE Recommended Practice for the Measurement of Potentially Hazardous Electromagnetic Fields - RF and Microwave" (Reference 15) specifies techniques and instrumentation for the measurement of fields both in the near-field and far-field of electromagnetic sources. Included also are a description of the concepts, techniques and instruments that can be applied to the measurement of SAR or electric field strength in organisms exposed to electromagnetic fields, and a brief treatment of body current measurements below 100 MHz.